CONFIDENTIAL

Copy
RM E52G31

NACA RM E52G31

RESEARCH MEMORANDUM

PERFORMANCE EVALUATION OF REDUCED-CHORD ROTOR BLADING AS APPLIED TO J73 TWO-STAGE TURBINE

I - OVER-ALL PERFORMANCE WITH STANDARD ROTOR BLADING AT INLET CONDITIONS OF 35 INCHES OF MERCURY ABSOLUTE AND 700° R

By William E. Berkey, John J. Rebeske, Jr., and Robert E. Forrette

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

July 11, 1957

[redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

PERFORMANCE EVALUATION OF REDUCED-CHORD ROTOR BLADING AS APPLIED TO J73 TWO-STAGE TURBINE

I - OVER-ALL PERFORMANCE WITH STANDARD ROTOR BLADING AT INLET CONDITIONS OF 35 INCHES OF MERCURY ABSOLUTE AND 700° R[1]

By William E. Berkey, John J. Rebeske, Jr., and Robert E. Forrette

SUMMARY

As a part of the performance evaluation of reduced-chord rotor blading as applied to the J73 two-stage turbine, an investigation was conducted to determine the over-all performance of this turbine with a standard rotor-blade configuration.

The turbine operated with a maximum brake internal efficiency between 0.91 and 0.92 at an over-all pressure ratio of about 3.4 and 120 percent equivalent design rotor speed. At 100 percent equivalent design speed and at a value of equivalent work output just sufficient to drive the compressor, the turbine operated with a brake internal efficiency of approximately 0.91 at an over-all pressure ratio of about 2.75. The equivalent weight flow passed by the turbine at this point is slightly higher than the equivalent design value. Limiting blade loading did not occur in the last rotor over the range of conditions investigated.

INTRODUCTION

An investigation is being conducted at the NACA Lewis laboratory to determine the over-all performance characteristics of various configurations of the turbine component from the J73 turbojet engine. The objective of this investigation is to determine the effects on turbine performance of reducing rotor-blade chord. With respect to weight, it would be advantageous to use short-chord blades in the engine, since their use would allow lighter weight rotor disks as well as less total blade weight. For a given turbine design, halving the blade chord will reduce the total turbine rotor weight by a factor of approximately two for similar blade profiles and constant solidity without appreciably changing the unit stress in either the blades or the rotor disk. Furthermore, any reduction in rotating mass will contribute favorably to the acceleration characteristics of the engine.

[1]The information presented herein was previously given limited distribution.

[redacted]

The investigation reported herein presents the over-all performance of the turbine using the standard blading configuration. The turbine was operated at a constant inlet stagnation pressure of 35 inches of mercury absolute and an inlet stagnation temperature of 700° R over a range of pressure ratios for equivalent rotational speeds of 20, 40, 60, 70, 80, 90, 100, 110, 120, and 130 percent of the equivalent design value. For an assumed flight Mach number of 0.8 the equivalent test altitude was approximately 18,000 feet, based on equal Reynolds numbers calculated from the critical velocity and critical density at the turbine inlet.

The performance is presented in terms of equivalent turbine-shaft work (based on torque measurements) and a weight-flow parameter for lines of constant equivalent rotor speed, pressure ratio, and brake internal efficiency. The curves of equivalent weight flow and equivalent torque, as well as a data-summary chart from which the over-all performance map is derived, are also presented. The equivalent design parameters are discussed in the appendix.

2610

SYMBOLS

The following symbols are used in this report:

A	area, sq ft
E	enthalpy drop based on torque measurements, Btu/lb
g	acceleration due to gravity, 32.174 ft/sec^2
J	mechanical equivalent of heat, 778 ft-lb/Btu
N	rotational speed, rpm
p	static pressure, in. Hg abs
p'	stagnation pressure, in. Hg abs
p'_x	static pressure plus velocity pressure corresponding to axial component of velocity, in. Hg abs
R	universal gas constant, 53.379 ft-lb/(lb)(°R)
T'	stagnation temperature, °R
V_{cr}	critical velocity, $\sqrt{\frac{2\gamma}{\gamma+1} gRT'}$
w	weight flow, lb/sec

$\frac{wN}{60\delta}\epsilon$ weight-flow parameter based on equivalent weight flow and equivalent rotational speed

γ ratio of specific heats, c_p/c_v

δ ratio of inlet-air pressure to NACA standard sea-level pressure, $p_1'/29.92$ in. Hg abs

ϵ function of γ, $$\frac{\gamma_0}{\gamma_e}\left[\frac{\left(\frac{\gamma_e+1}{2}\right)^{\frac{\gamma_e}{\gamma_e-1}}}{\left(\frac{\gamma_0+1}{2}\right)^{\frac{\gamma_0}{\gamma_0-1}}}\right]$$

η_i brake internal efficiency defined as ratio of actual turbine work based on torque measurements to ideal turbine work based on inlet stagnation pressure p_1' and outlet stagnation pressure corrected for whirl $p_{x,2}'$

θ_{cr} squared ratio of critical velocity to critical velocity at NACA standard sea-level temperature of 518.4° R, $(V_{cr,e}/V_{cr,0})^2$

τ torque, ft-lb

Subscripts:

cr critical

e engine operating conditions

x axial

0 NACA standard sea-level conditions

1 turbine-inlet measuring station

2 turbine-outlet measuring station

APPARATUS

Turbine. - Information supplied by the manufacturer shows that the two-stage turbine for the J73 turbojet engine is designed for the following conditions:

	Engine sea-level design conditions (zero ram)	Equivalent design conditions
Weight flow, lb/sec	138.7	42.05
Rotational speed, rpm	7950	4041
Inlet temperature, ^{o}R	2060	518.4
Inlet pressure, in. Hg abs	201	29.92

2610

The two-stage turbine was designed with a constant pitch-line diameter equal to 25.50 inches. The first stage has an annulus outside diameter of 29.50 inches and a hub-tip radius ratio of about 0.73. The flow passage then diverges through the second stator as shown in figure 1 to a turbine-tip diameter of 31.00 inches, with a hub-tip radius ratio of about 0.65.

Power absorber. - Two cradled dynamometers of the eddy-current wet-gap type connected in tandem were used to absorb the output of the turbine. The turbine torque output was measured by means of a calibrated NACA balanced-diaphragm-type thrust meter.

Test installation. - The experimental turbine setup is shown in figure 2. Air flow to the unit was supplied by the laboratory combustion-air system at 110 inches of mercury absolute and passed through a submerged orifice. After metering, the air was throttled to approximately 35 inches of mercury absolute and heated by means of two standard jet-engine burners to about 700^{o} R. The air flow was divided and entered a plenum chamber (see fig. 1), which replaced the normal combustor assembly of the engine, through two 20-inch-diameter openings spaced 180^{o} apart at right angles to the turbine shaft. The air was then turned and passed through a section of straightening tubes located 10 inches upstream of the first stator section. It then passed through the first and second stages of the turbine into the tail cone, whence it was discharged into the laboratory exhaust system.

INSTRUMENTATION

Turbine weight flow. - The air weight flow was measured by a calibrated submerged A.S.M.E. flange-tap flat-plate orifice. Fuel flow to the burners was measured by a calibrated rotameter located in the fuel line.

Turbine instrumentation. - The gas state in the turbine was measured at the two axial stations shown in figure 1, station 1 being upstream of the first stator and station 2 being downstream of the second rotor. The turbine-inlet temperature was measured with 12 calibrated spike-type thermocouples, arranged 3 to a rake, the thermocouples being on centers of equal annular areas and the rakes spaced 90° apart around the annulus. Bisecting the angle between the thermocouple rakes were 4 stagnation-pressure rakes, each rake having 3 probes located at the same radii as
2610 the thermocouples. Static pressures were measured by 16 taps located around the annulus, 8 taps each on the inner and outer walls. The turbine-exit conditions were measured by 10 calibrated spike-type thermocouples arranged 5 to a rake on centers of equal annular areas; 5 Kiel-type total-pressure probes, located at different circumferential positions and on centers of equal annular areas; and 8 static-pressure taps, 4 each on the inner and outer walls, equally spaced around the annulus and opposite each other on the inner and outer walls.

Precision. - The precision of the test measurements is estimated to be within the following limits:

Temperature, °R	±1.0
Pressure, in. Hg abs.	±0.05
Air weight flow, percent.	±1.0
Rotor speed, percent.	±0.5
Torque, percent	±0.5

The cumulative effect on calculated turbine efficiency, from measurements of the foregoing precision, would give a maximum error of ±2.0 percent at equivalent design conditions.

METHODS AND PROCEDURE

Variations in the ratio of specific heats from the design turbine-inlet temperature to standard sea-level temperature were of sufficient magnitude to warrant consideration along with the variations in temperature in determining the equivalent conditions of the turbine. Mach numbers through the turbine were close to a value of 1.0; hence an approximation of equivalent conditions could be obtained by a method based on critical velocity determined from the stagnation temperature at the turbine inlet and an average equilibrium value of γ. Derivation of this method is presented in the appendix.

A uniform circumferential distribution of pressure was not obtained at the turbine inlet, because the flow-straightening tubes (see fig. 1) did not offer enough resistance to the flow. The measured values of inlet stagnation pressure were considered not to be of sufficient accuracy, since the instrument rakes were spaced 90° apart around the annulus. The static-pressure taps were located every 45° around the annulus, and the inlet stagnation pressure p_1' was calculated from the average value of these readings together with the known annulus area, the inlet stagnation temperature, and the orifice weight flow. This calculated value was found to be approximately 0.8 inches of mercury lower than the measured value over the range of conditions investigated.

The pressure $p_{x,2}'$ is defined as the static pressure behind the second rotor plus the velocity pressure corresponding to the axial component of the absolute velocity at the exit from the turbine. This calculated value of turbine-exit stagnation pressure charged the turbine for the energy of the whirl component existent in the exit velocity of the gas. Uniform flow was assumed, which further charged the turbine for the unavailable energy represented by velocity variations at the turbine exit. This pressure was calculated from the general energy equation and continuity by using the known annulus area at the measuring station and measured values of weight flow, static pressure, stagnation pressure, and stagnation temperature. 2610

The turbine was operated at constant inlet stagnation pressure and temperature of approximately 35 inches of mercury absolute and 700° R, respectively, for equivalent rotational speeds of 20, 40, 60, 70, 80, 90, 100, 110, 120, and 130 percent of the equivalent design value over a range of over-all pressure ratios $p_1'/p_{x,2}'$ from 1.4 to 4.0.

RESULTS AND DISCUSSION

The over-all performance of the J73 two-stage turbine is presented in terms of equivalent shaft work, equivalent weight flow, brake internal efficiency, equivalent stagnation-pressure ratio, and percentage of equivalent design rotor speed.

A composite map (fig. 3) shows the over-all performance of the turbine in terms of equivalent shaft work E/θ_{cr} and a weight-flow parameter $\frac{wN}{60\delta}\epsilon$ for lines of constant equivalent pressure ratio $p_1'/p_{x,2}'$ and constant equivalent rotor speed $N/\sqrt{\theta_{cr}}$ with contour lines showing the brake-internal-efficiency levels η_1.

Information supplied by the manufacturer shows that the turbine is designed to drive a compressor with a pressure ratio of 7 and an efficiency of 0.84 at design speed and design pressure ratio. This results in an equivalent work E/θ_{cr} requirement of 28.48 Btu per pound, neglecting leakage and fuel flow. Plotting this value of equivalent work on figure 3 at 100 percent equivalent design speed shows the turbine to be operating with a brake internal efficiency of about 0.91 at an over-all pressure ratio of about 2.75. A maximum brake internal efficiency between 0.91 and 0.92 was obtained at a pressure ratio of about 3.4 and 120 percent equivalent design speed.

The variation of equivalent weight flow with over-all pressure ratio for a range of equivalent rotor speeds is presented in figure 4. The figure indicates that above an over-all pressure ratio of about 2.9, the turbine is choked for all values of equivalent design speed investigated. However, the choking weight flow is shown to increase with a decrease in rotor speed (except for low rotor speeds where the stator chokes), indicating that at the high values of pressure ratio and high rotor speeds the choke point is somewhere downstream of the first stator.

At the operating point of 100 percent equivalent design speed and an over-all pressure ratio of 2.75, the equivalent weight flow is approximately 42.65 pounds per second. This value is slightly higher than the equivalent design value of 42.05 pounds per second. At 100 percent equivalent design speed, the equivalent weight flow remains constant at a value of about 42.65 pounds per second for all values of over-all pressure ratio $p_1'/p_{x,2}'$ above 2.7.

The variation of equivalent torque with over-all pressure ratio for various equivalent rotor speeds is shown in figure 5. For the range of conditions investigated, the figure shows that values of equivalent torque $\frac{\tau}{\delta}\epsilon$ are still increasing with an increase in over-all pressure ratio $p_1'/p_{x,2}'$, indicating that limiting blade loading in the last rotor was not reached. Limiting blade loading is discussed in reference 1. Additional information from the investigation is presented in the form of a data summary, table I. This table gives values of $p_1'/p_{x,2}'$, p_1'/p_2', p_1'/p_2, p_1', T_1', T_2', N, w, and τ, from which all points on the over-all performance map (fig. 3) were derived.

SUMMARY OF RESULTS

From an investigation of the over-all performance of the J73 two-stage turbine, the following results were obtained:

1. At 100 percent equivalent design speed and a value of equivalent work output just sufficient to drive the compressor, the turbine operated with a brake internal efficiency of approximately 0.91 at an over-all pressure ratio of about 2.75.

2. A peak brake internal efficiency between 0.91 and 0.92 was obtained at an over-all pressure ratio of about 3.4 and 120 percent equivalent design rotor speed.

3. At the operating point of 100 percent equivalent design speed and an over-all pressure ratio of 2.75, the equivalent weight flow was approximately 42.65 pounds per second. This value is slightly higher than the equivalent design value.

4. Limiting blade loading did not occur in the last rotor over the range of conditions investigated. 2610

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio

APPENDIX - METHOD OF APPROXIMATING EQUIVALENT DESIGN CONDITIONS

Information on the effect of heat-capacity lag in turbine nozzles presented in reference 2 indicates that for some typical turbines used in turbojet engines the vibrational energy of the gas molecules is unavailable in the expansion process. This condition corresponds to a constant γ value of 1.4. However, examination of the results of reference 2 indicates that the actual flow processes of this particular turbine may be more closely approximated by using the equilibrium value of γ, since this multistage machine has a high pressure level (compressor pressure ratio of 7) and an increased flow path through the turbine. Consequently, an average equilibrium γ value of 1.315 was selected as representative.

Determination of equivalent weight flow. - The equation of continuity may be written in terms of critical velocity V_{cr}, area A_{cr}, and density ρ_{cr}, and solved for the critical area as follows:

$$A_{cr} = \frac{w_{cr}V_{cr}}{p'g}\frac{1}{\gamma}\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}} \tag{1}$$

The critical area for turbine operating conditions is equated to the critical area for NACA standard sea-level conditions at the turbine inlet to obtain

$$\frac{w_{cr,e}V_{cr,e}}{p_e'}\frac{1}{\gamma_e}\left(\frac{\gamma_e+1}{2}\right)^{\frac{\gamma_e}{\gamma_e-1}} = \frac{w_{cr,0}V_{cr,0}}{p_0'}\frac{1}{\gamma_0}\left(\frac{\gamma_0+1}{2}\right)^{\frac{\gamma_0}{\gamma_0-1}} \tag{2}$$

Solving for the critical weight flow at NACA standard sea-level conditions yields the following equation:

$$w_{cr,0} = \frac{w_{cr,e}\frac{V_{cr,e}}{V_{cr,0}}}{\frac{p_e'}{p_0'}}\frac{\gamma_0}{\gamma_e}\left[\frac{\left(\frac{\gamma_e+1}{2}\right)^{\frac{\gamma_e}{\gamma_e-1}}}{\left(\frac{\gamma_0+1}{2}\right)^{\frac{\gamma_0}{\gamma_0-1}}}\right] \tag{3}$$

Equation (3) may be written

$$w_{cr,0} = \frac{w_{cr,e}\sqrt{\theta_{cr}}}{\delta}\,\epsilon \tag{4}$$

The variation of ϵ as a function of γ is shown in figure 6.

Determination of equivalent work. - The work output of a turbine rotor-blade row may be expressed by the following equation:

2610

$$E = \eta_1 \frac{\gamma}{\gamma-1} \frac{R}{J} T_1' \left[1 - \left(\frac{p_{x,2}'}{p_1'}\right)^{\frac{\gamma-1}{\gamma}}\right] \tag{5}$$

Dividing equation (5) by V_{cr}^2 and simplifying gives

$$\frac{E}{V_{cr}^2} = \eta_i \frac{\gamma+1}{2(\gamma-1)g}\left[1 - \left(\frac{p_{x,2}'}{p_1'}\right)^{\frac{\gamma-1}{\gamma}}\right] \tag{6}$$

Equating $E_0/V_{cr,0}^2$ for standard sea-level conditions to $E_e/V_{cr,e}^2$ for engine operating conditions gives

$$\frac{E_0}{V_{cr,0}^2} = \frac{E_e}{V_{cr,e}^2} \tag{7}$$

Combining equation (7) with equation (6) gives

$$\eta_{i,0}\frac{\gamma_0+1}{\gamma_0-1}\frac{1}{2g}\left[1 - \left(\frac{p_{x,2}'}{p_1'}\right)_0^{\frac{\gamma_0-1}{\gamma_0}}\right] = \eta_{i,e}\frac{\gamma_e+1}{\gamma_e-1}\frac{1}{2g}\left[1 - \left(\frac{p_{x,2}'}{p_1'}\right)_e^{\frac{\gamma_e-1}{\gamma_e}}\right] \tag{8}$$

If it is assumed that the turbine efficiency η_i does not change, then

$$\frac{\gamma_0+1}{\gamma_0-1}\left[1 - \left(\frac{p_{x,2}'}{p_1'}\right)_0^{\frac{\gamma_0-1}{\gamma_0}}\right] = \frac{\gamma_e+1}{\gamma_e-1}\left[1 - \left(\frac{p_{x,2}'}{p_1'}\right)_e^{\frac{\gamma_e-1}{\gamma_e}}\right] \tag{9}$$

To preserve the equality of equation (9) as γ changes, the pressure ratio must vary. Figure 7 shows the variation of the ratio of the pressure ratio at standard conditions to the pressure ratio at engine operating conditions as a function of γ for various constant values of each pressure ratio.

REFERENCES

1. Hauser, Cavour H., and Plohr, Henry W.: Two-Dimensional Cascade Investigation of the Maximum Exit Tangential Velocity Component and Other Flow Conditions at the Exit of Several Turbine Blade Designs at Supercritical Pressure Ratios. NACA RM E51F12, 1951.

2. Spooner, Robert B.: Effect of Heat-Capacity Lag on a Variety of Turbine-Nozzle Flow Processes. NACA TN 2193, 1950.

TABLE I - DATA SUMMARY FROM EXPERIMENTAL INVESTIGATION OF J73 TWO-STAGE TURBINE WITH STANDARD ROTOR BLADING

Calculated over-all total to total pressure ratio $p_1'/p_{x,2}'$	Over-all total to total pressure ratio p_1'/p_2'	Over-all total to static pressure ratio p_1'/p_2	Inlet stagnation pressure p_1' (in. Hg abs)	Inlet stagnation temperature T_1' (°R)	Outlet stagnation temperature T_2' (°R)	Engine speed N (rpm)	Weight flow w (lb/sec)	Torque τ (ft-lb)
1.338	1.314	1.375	34.59	700.0	664.9	944	38.44	2159
1.346	1.343	1.381	34.84	700.2	653.3	1888	37.48	1613
1.343	1.332	1.372	34.84	699.0	646.5	2828	35.39	1111
1.359	1.338	1.390	34.78	700.0	648.0	3294	34.72	952.5
1.366	1.323	1.395	35.08	699.9	650.3	3780	34.79	783.4
1.362	1.306	1.391	34.89	699.0	656.0	4238	33.92	587.4
1.369	1.293	1.398	34.83	699.9	662.7	4710	33.59	456.0
1.374	1.286	1.404	35.10	699.9	670.2	5186	33.73	314.2
1.380	1.288	1.410	34.96	699.7	677.7	5652	33.17	205.3
1.512	1.465	1.573	34.78	699.3	657.2	942	41.30	2909
1.514	1.508	1.572	34.64	699.9	638.4	1886	40.53	2264
1.515	1.512	1.568	34.72	700.9	631.0	2825	39.24	1691
1.526	1.506	1.578	34.89	698.2	626.4	3290	38.60	1445
1.525	1.497	1.576	34.90	699.8	629.2	3773	38.11	1249
1.542	1.487	1.593	35.07	700.4	632.5	4245	37.62	1053
1.528	1.445	1.576	34.60	700.2	638.8	4714	36.90	828.8
1.542	1.444	1.590	34.89	699.4	643.2	5192	36.72	681.6
1.548	1.425	1.597	35.13	700.2	651.7	5660	36.70	533.8
1.546	1.407	1.595	34.79	699.2	659.5	6140	36.22	370.1
1.682	1.606	1.772	34.47	701.0	652.8	932	41.96	3350
1.699	1.680	1.788	34.59	701.6	627.3	1892	41.83	2776
1.690	1.675	1.772	34.47	698.4	613.2	2835	41.18	2180
1.717	1.712	1.801	34.86	700.1	610.0	3314	41.03	1967
1.706	1.675	1.786	34.41	700.1	610.5	3780	39.94	1660
1.716	1.671	1.794	34.81	700.1	611.2	4252	39.92	1464
1.727	1.654	1.807	34.56	700.9	614.8	4716	39.55	1261
1.742	1.640	1.821	35.00	699.9	618.4	5195	39.34	1076
1.740	1.606	1.819	34.62	700.5	625.3	5658	38.90	889.6
1.744	1.580	1.824	34.75	700.6	633.6	6135	38.82	730.8

NACA

2610

TABLE I - DATA SUMMARY FROM EXPERIMENTAL INVESTIGATION OF J73 TWO-STAGE TURBINE WITH STANDARD ROTOR BLADING - Continued

Calculated over-all total to total pressure ratio $p_1'/p_{x,2}'$	Over-all total to total pressure ratio p_1'/p_2'	Over-all total to static pressure ratio p_1'/p_2	Inlet stagnation pressure p_1' (in. Hg abs)	Inlet stagnation temperature T_1' (°R)	Outlet stagnation temperature T_2' (°R)	Engine speed N (rpm)	Weight flow w (lb/sec)	Torque τ (ft-lb)
1.995	1.825	2.153	34.84	700.8	642.6	951	43.00	3919
2.060	1.985	2.232	34.60	699.9	610.8	1878	43.06	3448
1.966	1.952	2.106	34.42	700.1	597.2	2822	42.34	2710
1.971	1.956	2.108	34.63	700.3	592.0	3298	42.17	2443
1.975	1.961	2.112	34.59	700.4	587.9	3780	41.95	2202
1.986	1.964	2.120	34.66	698.4	585.5	4250	41.46	1929
1.992	1.938	2.126	34.52	699.7	588.3	4714	41.17	1715
2.012	1.920	2.144	34.74	700.2	591.3	5194	40.69	1491
2.000	1.880	2.128	34.68	700.4	597.2	5652	40.22	1311
2.012	1.836	2.140	34.89	697.8	602.1	6132	40.22	1103
2.174	2.073	2.376	34.33	698.5	604.9	1880	42.53	3561
2.237	2.206	2.450	34.59	700.5	584.1	2830	42.62	3107
2.201	2.179	2.397	34.64	699.7	577.0	3296	42.55	2801
2.196	2.174	2.389	34.55	700.6	575.7	3772	42.27	2516
2.214	2.197	2.407	34.80	700.7	571.9	4248	42.24	2264
2.214	2.178	2.402	34.54	699.4	569.2	4724	41.56	1996
2.236	2.164	2.428	34.84	700.9	575.3	5186	41.63	1788
2.235	2.129	2.424	34.42	700.5	577.0	5660	40.96	1564
2.219	2.069	2.401	34.60	700.5	583.5	6128	40.79	1345
2.458	2.373	2.750	34.29	700.0	574.4	2822	42.45	3309
2.445	2.417	2.728	34.13	700.6	564.5	3310	42.42	3057
2.477	2.438	2.762	34.55	699.7	558.4	3774	42.48	2806
2.474	2.446	2.756	34.61	700.1	555.5	4236	42.43	2565
2.481	2.463	2.759	34.71	700.8	552.9	4714	42.35	2313
2.508	2.456	2.794	34.56	699.1	551.4	5191	42.06	2067
2.526	2.447	2.815	34.63	699.5	554.8	5650	41.82	1865
2.525	2.402	2.811	34.57	699.7	561.6	6135	41.41	1635

NACA

[redacted]

TABLE I - DATA SUMMARY FROM EXPERIMENTAL INVESTIGATION OF J73 TWO-STAGE TURBINE

WITH STANDARD ROTOR BLADING - Concluded

Calculated over-all total to total pressure ratio $p_1'/p_{x,2}'$	Over-all total to total pressure ratio p_1'/p_2'	Over-all total to static pressure ratio p_1'/p_2	Inlet stagnation pressure p_1' (in. Hg abs)	Inlet stagnation temperature T_1' (°R)	Outlet stagnation temperature T_2' (°R)	Engine speed N (rpm)	Weight flow w (lb/sec)	Torque (ft-lb)
2.849	2.619	3.330	34.47	700.8	562.6	2822	42.79	3643
2.899	2.780	3.399	34.64	699.4	549.7	3304	42.79	3408
2.833	2.794	3.292	34.53	700.9	544.3	3764	42.71	3118
2.849	2.789	3.302	34.47	700.1	536.9	4250	42.46	2855
2.854	2.799	3.296	34.71	699.8	534.9	4722	42.29	2636
2.867	2.837	3.313	34.75	699.5	532.9	5188	42.30	2423
2.877	2.830	3.321	34.90	699.6	534.4	5656	42.09	2160
2.889	2.800	3.337	34.81	699.8	537.1	6138	42.02	1936
3.187	2.820	3.898	34.77	700.7	546.2	2830	43.10	3948
3.228	2.921	3.957	34.70	700.1	533.0	3300	43.04	3702
3.218	3.095	3.933	34.85	700.4	524.9	3775	43.10	3451
3.206	3.106	3.889	34.88	700.9	518.6	4248	42.94	3183
3.244	3.120	3.929	34.97	701.5	509.7	4720	42.87	2950
3.244	3.171	3.921	35.13	701.3	509.7	5190	42.82	2709
3.268	3.215	3.960	35.36	701.4	512.3	5658	42.83	2496
3.325	3.262	4.057	34.81	701.3	509.7	6140	42.02	2255
3.612	2.972	4.799	34.41	701.4	539.2	2825	42.64	4053
2.700	3.079	4.977	34.39	701.5	524.3	3300	42.59	3829
3.627	3.269	4.770	34.49	701.3	515.3	3776	42.51	3572
3.639	3.415	4.777	34.63	702.5	508.3	4248	42.51	3349
3.670	3.407	4.809	34.72	700.5	501.5	4716	42.54	3097
3.694	3.516	4.848	34.81	701.3	497.8	5182	42.46	2878
3.714	3.590	4.881	35.00	701.5	496.8	5658	42.46	2672
3.662	3.538	4.743	34.81	700.4	498.5	6130	42.08	2448
3.768	3.313	5.156	34.29	703.1	513.6	3775	42.39	3623
3.834	3.532	5.319	34.47	701.0	505.0	4247	42.47	3394
3.921	3.550	5.515	34.58	701.0	498.4	4720	42.43	3159
3.858	3.613	5.283	34.76	701.5	495.6	5183	42.39	2924
3.814	3.649	5.129	34.67	700.6	494.7	5660	42.04	2683
3.829	3.656	5.143	34.77	701.0	494.8	6125	51.94	2590
3.908	3.550	5.460	34.51	701.3	499.2	4712	42.25	3210
3.998	3.652	5.701	34.66	700.4	493.4	5194	42.25	2914
4.108	3.791	6.056	34.88	702.2	492.1	5658	42.16	2733
4.174	3.869	6.325	34.98	700.9	489.9	6125	42.16	2640

NACA

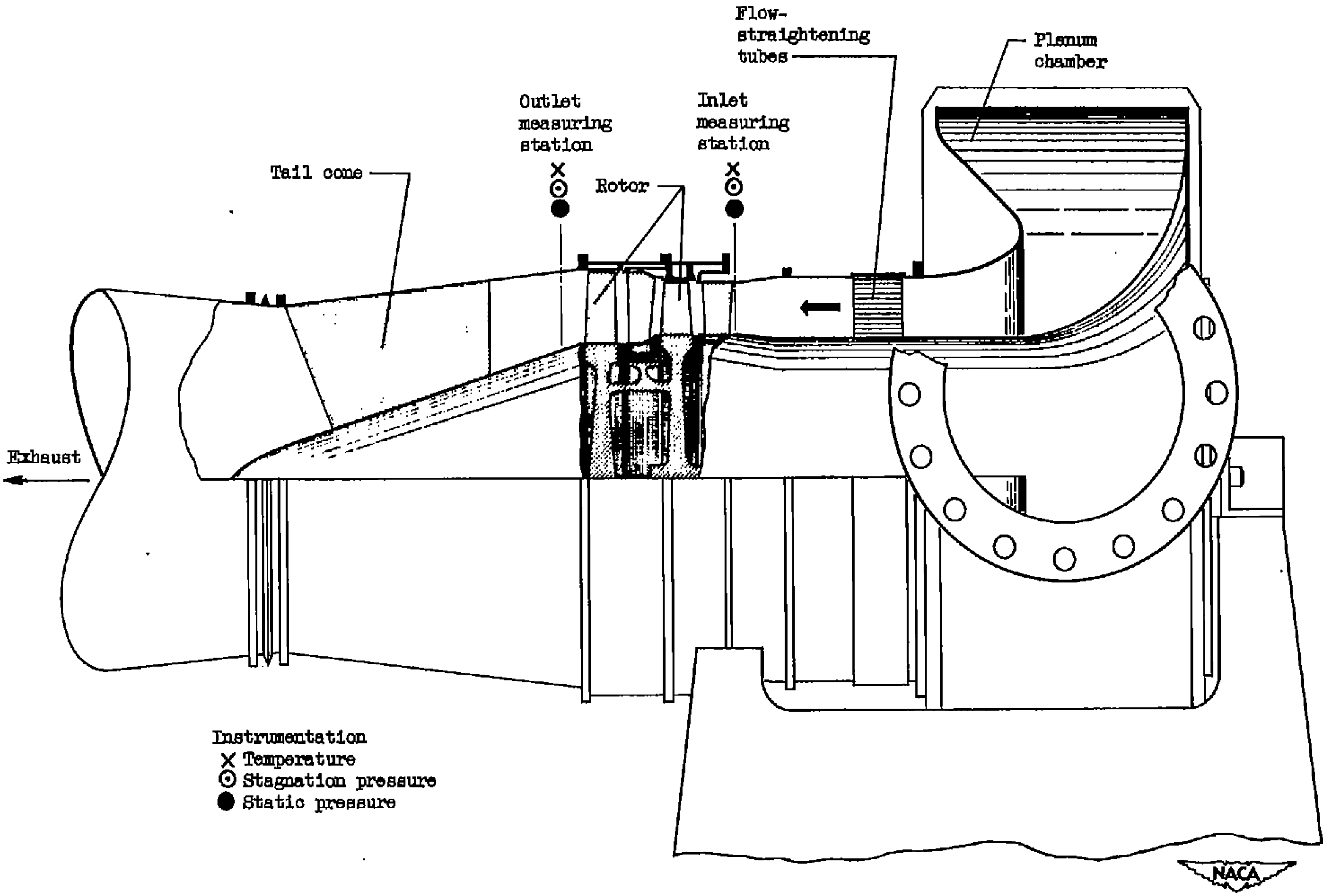

Figure 1. - Schematic diagram of turbine assembly and instrumentation.

2610

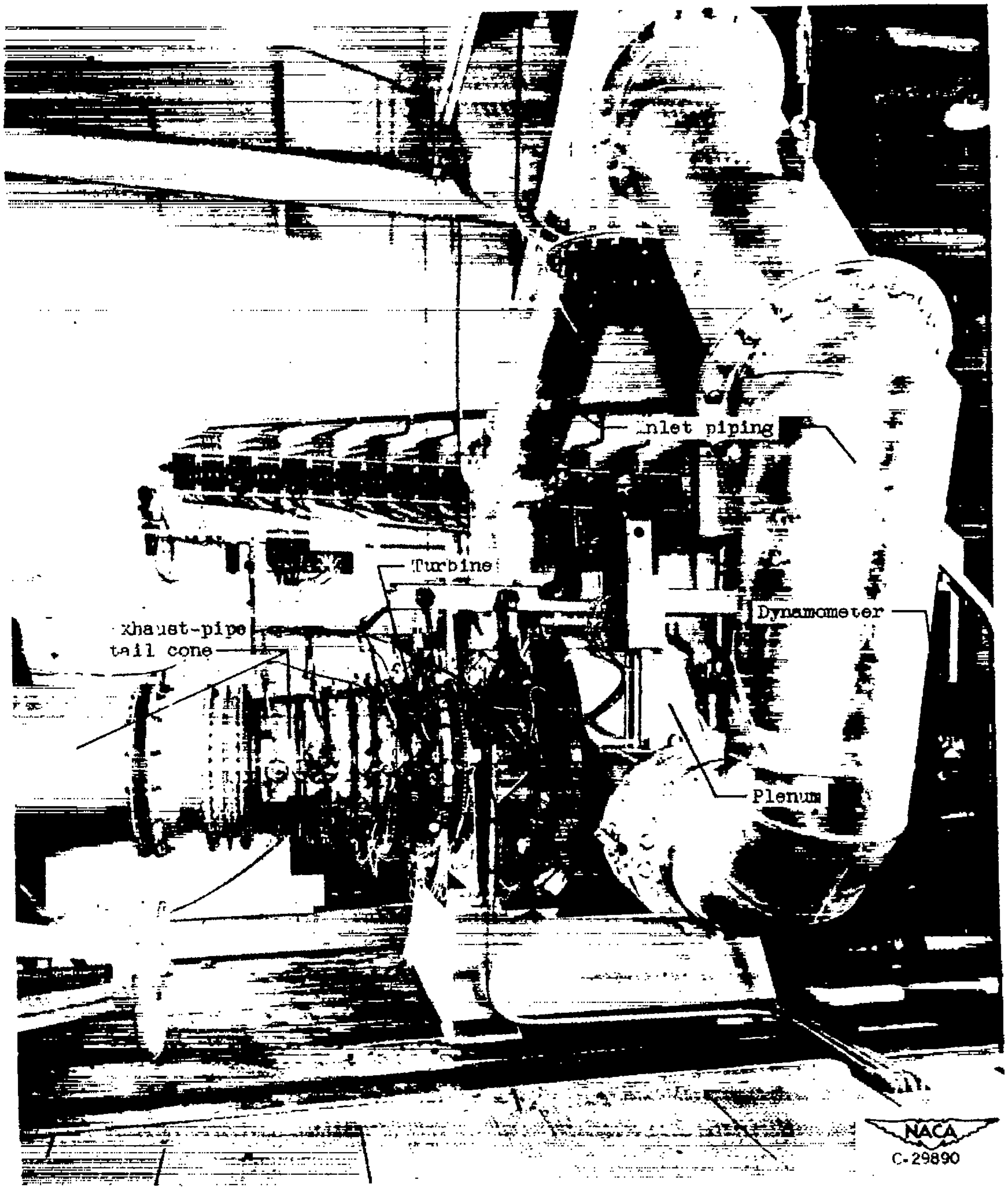

Figure 2. - Installation for experimental investigation of J73 two-stage turbine showing inlet plenum, power absorbers, and instrumentation.

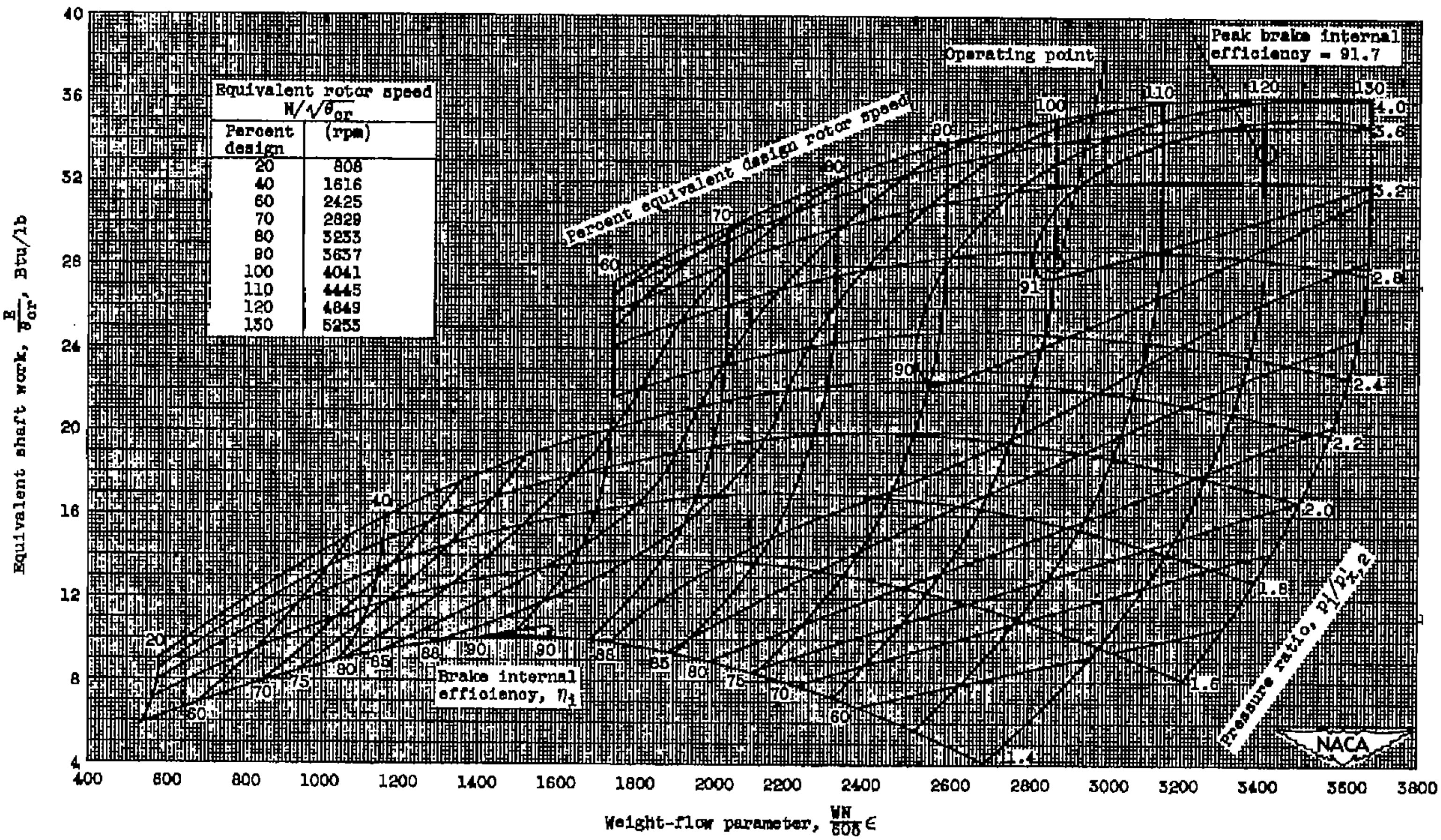

Figure 3. - Over-all performance of J73 two-stage turbine with standard rotor blading. Turbine-inlet pressure, 35 inches of mercury absolute; turbine-inlet temperature, 700° R.

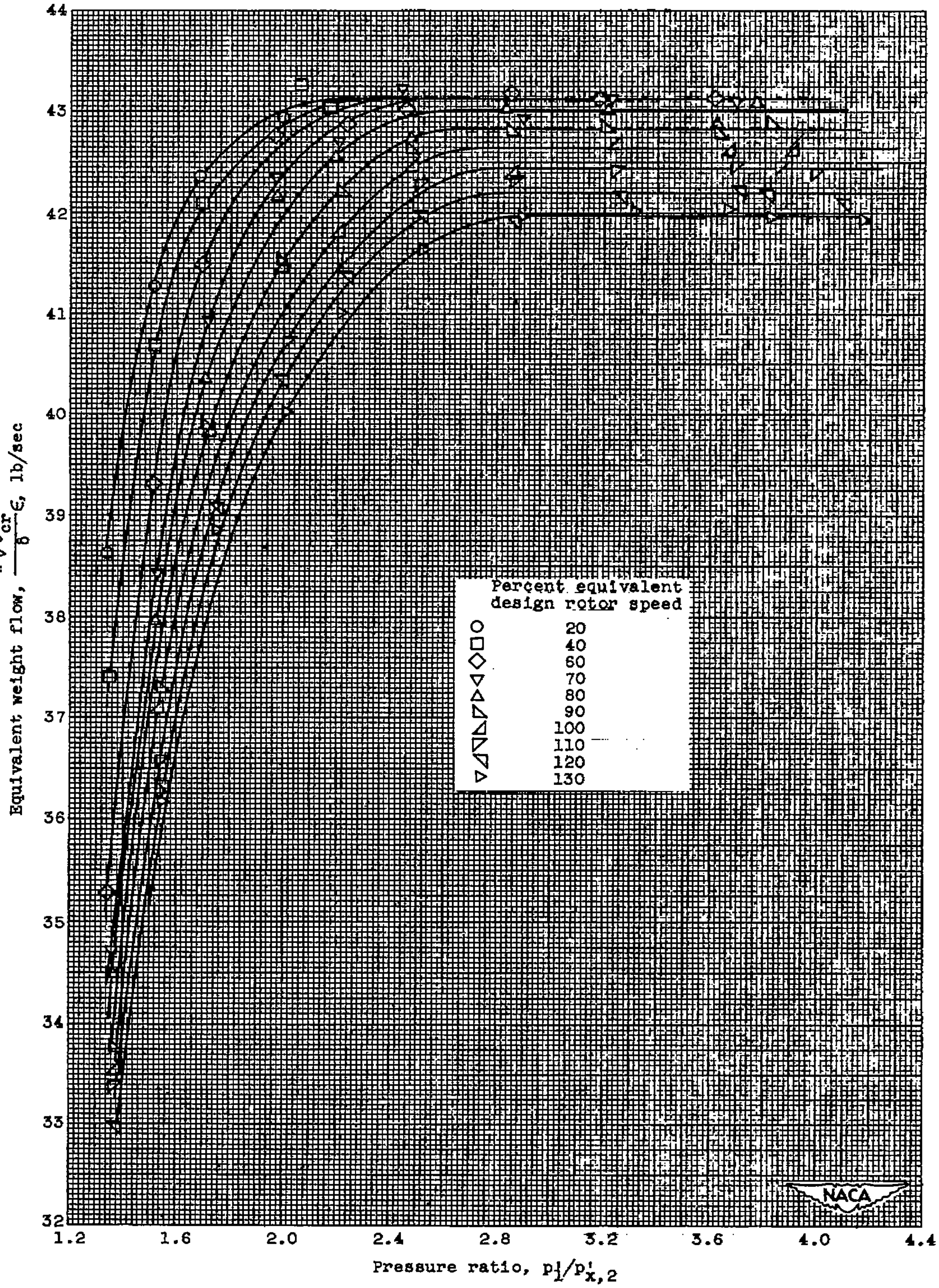

Figure 4. - Variation of equivalent weight flow with over-all pressure ratio for lines of constant equivalent rotor speed.

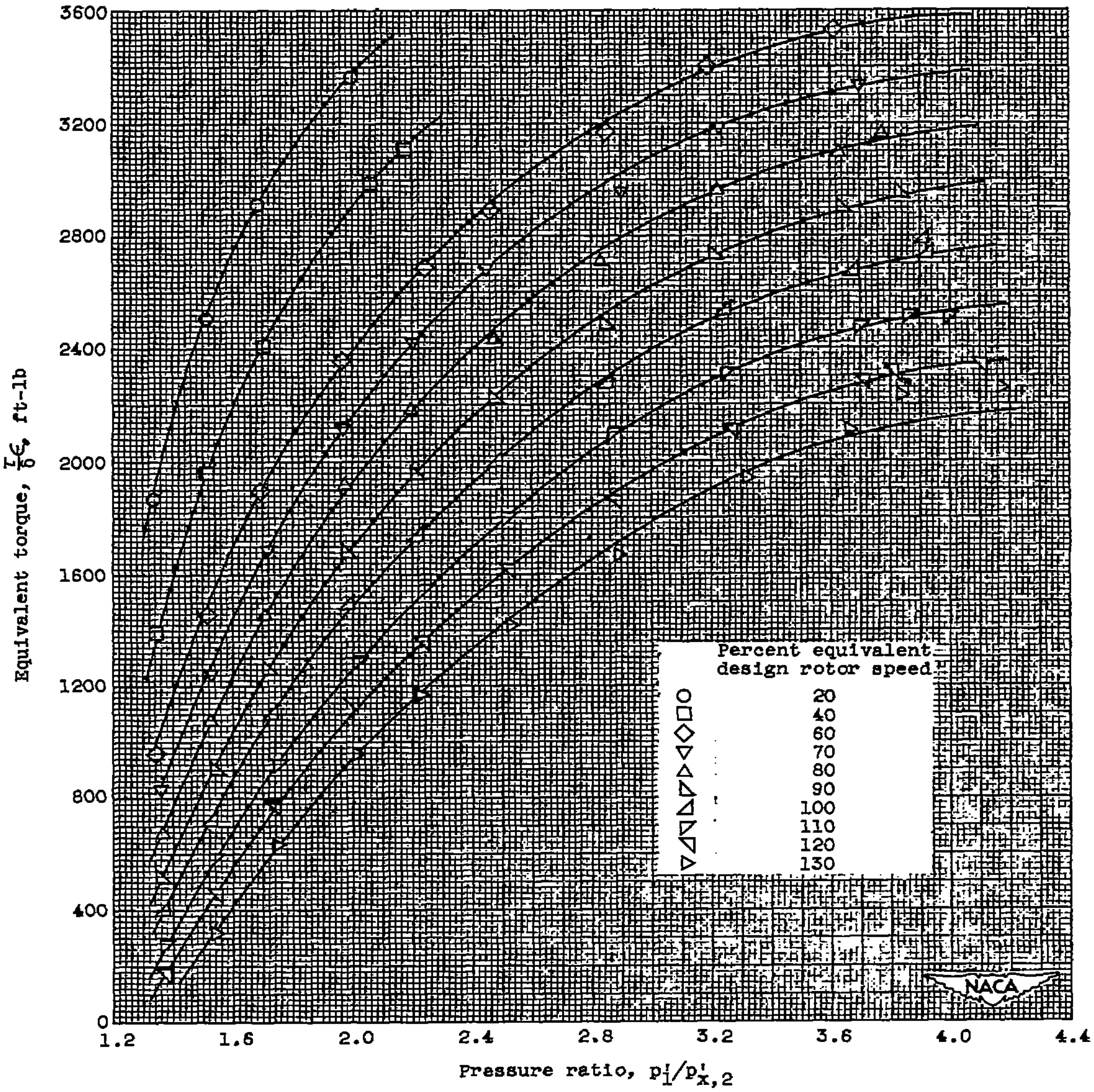

Figure 5. - Variation of equivalent torque with over-all pressure ratio for lines of constant equivalent rotor speed.

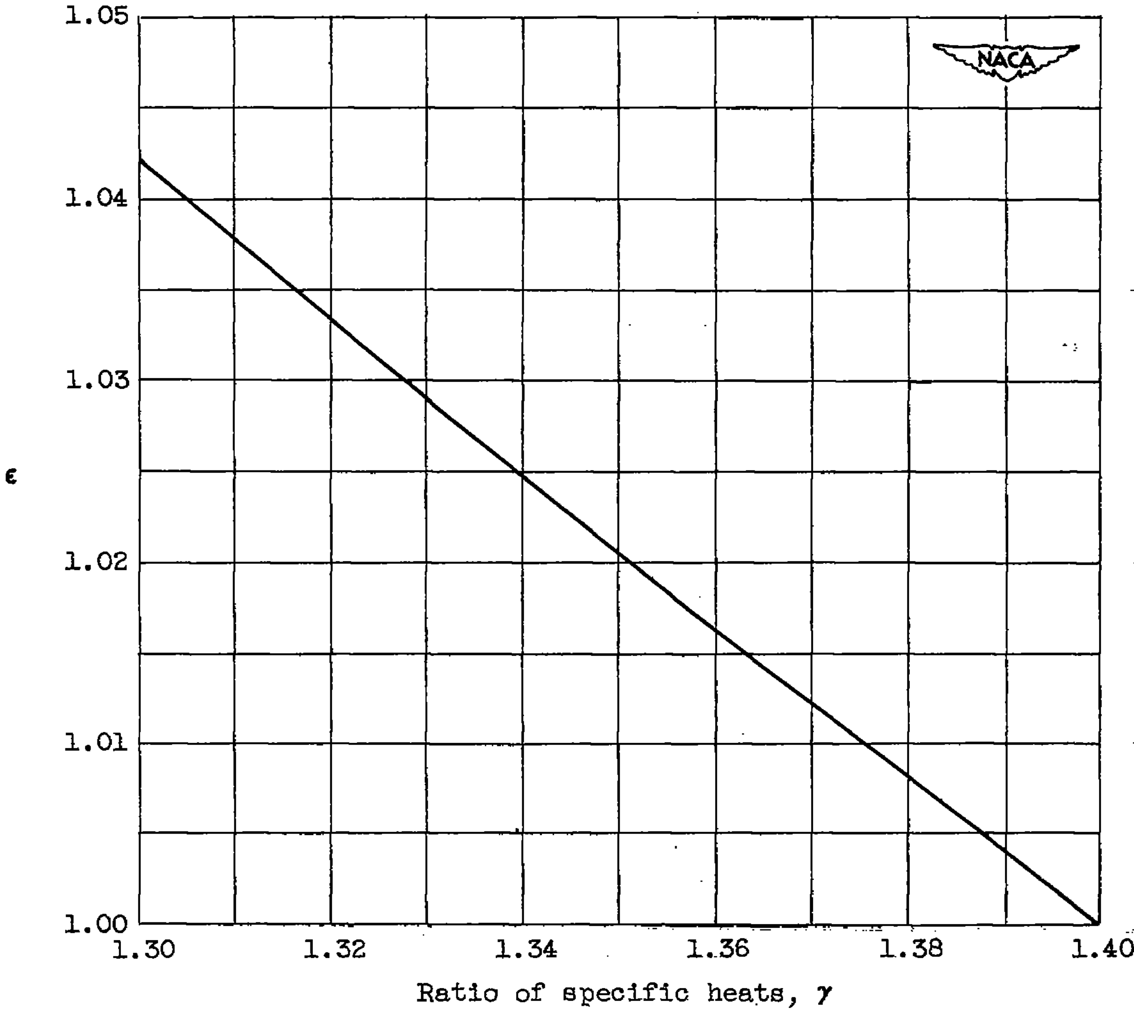

Figure 6. - Variation of ϵ as a function of ratio of specific heats.

2610

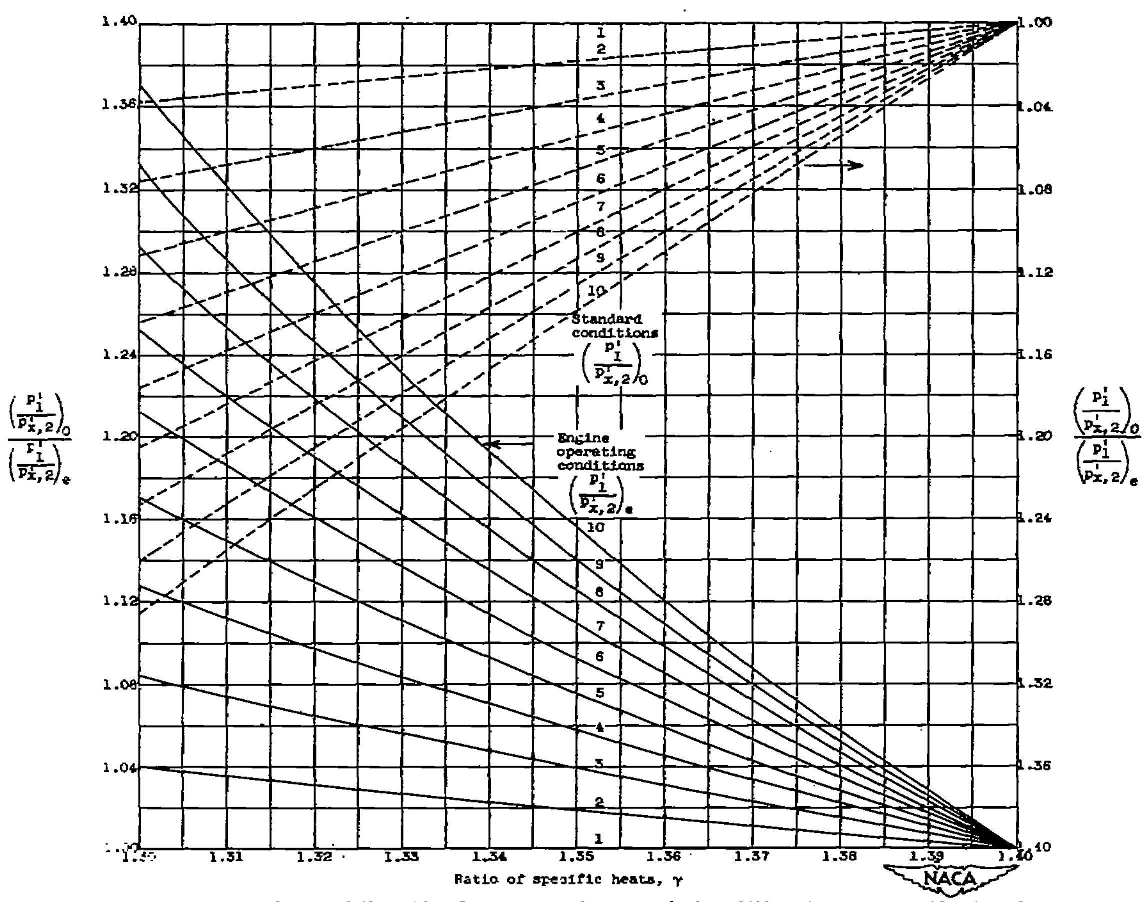

Figure 7. - Variation of the ratio of pressure ratio at standard conditions to pressure ratio at engine conditions with ratio of specific heats.

[redacted]

[redacted]

[redacted]